Influence of Urban Green Spaces on Road Traffic Noise Levels: - A Review

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ABSTRACT:

Ninety per cent of urban areas' total noise pollution is caused by traffic. Green areas are a very important factor for noise reduction. They will absorb noise from 5dB (A) to 10 dB (A). Nonetheless, some major concerns can be addressed, such as: how can green areas be established in the urban city?, how trees absorb noise?, what are the equations to calculate noise absorption by trees?, and what are the best survey methods to measure the trees' properties?, and is it possible to visualize trees in three-dimensional (3D) space?. Thirty-five (35) research papers were selected under the subtopics, green spaces and urban forms, noise absorption by green spaces, and green spaces visualization in 3D to find solutions for the above problems. The review has identified how to increase green spaces in urban forms like core, star, satellite, and linear. Next, the leaves are the main possible part to absorb noise, and depend on the leaves' surface area, tree depth, and noise absorption coefficient. These parameters must be considered to formulate an equation to identify sound absorption by leaves. Furthermore, the Light Detection and Ranging (LiDAR) technique can be used for determining the surface area of leaves and tree depth, due to its high resolution of point clouds. The Digital Surface Model (DSM) is not applicable for visualizing green areas, because it represents the only top view of trees, and tree depth cannot be identified properly. Proper visualization of green spaces in 3D will convey a significant point of view to visualize noise absorption accurately in a 3D urban city.

1. INTRODUCTION

Environmental noise pollution is a key global issue for all humans living on the earth (Iglesias-Merchan et al., 2021). According to the World Health Organization (WHO) definition, noise pollution is the third most impact on society after air and water pollution (Basu et al., 2021). Traffic noise pollution is 90% of total noise levels in developed urban cities, while it occurs at 10% in commercial, industrial, and residential activities (Vinaykumar Kurakula, 2007). The green areas can control the road traffic noise in a large city. Especially green open space is a possible factor in reducing road traffic noise levels.

Physical open spaces can be divided into natural and non-natural green areas (Aditya, Masykuri, and Setyono, 2019). The high spread of urbanization has led to changes in ecosystem services of the environment, and has been a problem of reducing the green spaces in urban city areas. To mitigate noise pollution, trees act as the main function to absorb, reflect and refract the noise levels. The trees' leaves, bark and branches are the main possible ways to resist the spreading noise levels in urban city areas (Ramyar et al., 2020). The well-grown plants, and the road play an important role in absorbing considerable traffic noise. Green areas are a very important factor for noise reduction, and will absorb noise from 5dB (A) to 10 dB (A) (Orikpete et al., 2021). Vegetation barriers along the roads in urban city areas can be affected to reduce noise levels from 10%-24% of total traffic noise levels (Li, Qiu, and Zheng, 2021). Most developed metropolitan cities use living green façade systems to reduce noise levels. Planting trees along the building façade and balcony areas reduce noise levels from the outside to the inside of buildings by more than 30 dB (Auer, Radi and Brkovi, 2019). The reduction of urban green spaces is a major problem for noise pollution. Due to the concept of compact cities, lands are used for optimum requirements. Leaves of trees are a very significant point of view for absorbing road traffic noise in urban city areas. The amount of noise absorption by a tree depends on the surface area of leaves, tree depth, and noise absorption coefficient of leaves.

1.1 Research Problem

Green spaces of urban city areas play the main role in reducing traffic noise pollution. Characteristics of trees and leaves affect noise reduction. Establishing green spaces in urban city areas will depend on the shape of the urban forms, and proper equations should be used to identify noise absorption by green areas. Traditional survey techniques are not enough to measure (three-dimensional) 3D green spaces. New survey approaches should be combined to detect trees' volume and visualize green spaces in 3D. The main objective of this research is to address the problems mentioned above and find solutions by reviewing previous research.

2. METHODOLOGY

For this paper, 100 research papers were collected to review the influence of green spaces and road traffic noise levels. Thirty-five (35) best research papers were selected to find solutions for the above problems through the review. Under the subtopics, green spaces and urban forms, noise absorption by green spaces, and green spaces visualization in 3D were associated with this review paper.

3. FINDINGS IN RESEARCH

3.1 Green Spaces and Urban Forms

Urbanization provides opportunities like economic growth, technology and transportation in modern city areas, and offers better social and health facilities and good employment

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opportunities. The major downside of urbanization is the deduction of green spaces in urban city areas. Green spaces in city areas provide capabilities to reduce noise pollution, and organized green spaces in urban cities significantly absorb road traffic noise. So, the urban city green spaces like parks, gardens, court yards and green belts along the roads should be inserted into the planning policies for the future developments (Ramaiah and Avtar, 2019).

There are limited land resources for green spaces due to the process of compact city developments. The major challenge for green spaces is long-term consolidated urbanization. The lack of green spaces in urban areas exposes people to mental and physical health disabilities. The major characteristics of compact cities are their high-density population, mixed land use, and building and roads with limited green spaces. Hong Kong and Singapore are significantly space-limited countries with rapidly compact development. Green spaces are a very important point of view in a compact city, because they provide quality ecosystem service (Sun et al., 2017). Due to its rapid urbanization and planning policies, the fragmentation of green spaces has been an intense issue in Beijing, China (Li et al., 2019). According to the estimation of the United Nations, 60% of the world population will live in urban city areas until 2050. It implies burdening the environment and natural resources due to the impact of a high population.

Although, there are many techniques to reduce road traffic noise pollution in urban cities, increasing the green spaces is an effective method because of its cost-effective method, and it will provide other benefits like clean air, urban temperature reduction and beautiful landscape. Before planning to establish green spaces in the city area, features of the natural environment and spatial layout of the area shall be considered. Green spaces can be planned along with roads network and land-use types in the urban city area. The previous literature reviews, have identified how to increase green spaces in urban forms like core, star, satellite, and linear. Figure 1 shows different type of green space distribution in urban city areas: (a) core type; (b) star style; (c) satellite type; (d) linear type.

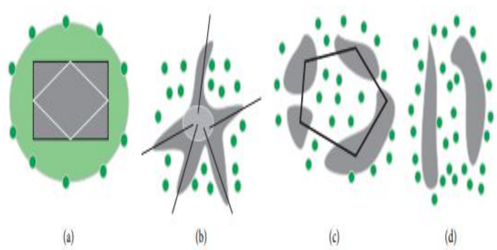

Figure 1. Green space distributions, (Shan et al., 2021)

Establishing green spaces will depend on the functioning area of the city. After examining city functions, urban planners can determine the areas for establishing green spaces in urban city areas. The remote sensing technique can be used with the Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) can be used for existing green spaces and the built-up area in the city. In core type urban forms, all the city functions are concentrated in the city centre. Therefore traffic noise is very high in the city centre, along the roads connected to the city centre. In star-type urban forms, all the functions have occurred as ring patterns. So, road traffic will be based on this ring pattern, in satellite type of urban forms, when city functions are concentrated in different city centres. Before establishing green areas to reduce noise pollution, we must consider road traffic in city centres. In linear urban forms, city functions are concentrated along the roads, and green spaces may be established along the roads as tree belts (Wijesundara, 2015).

The green areas in core-type cities exist as belts or dots and green patches in an artificially constructed environment. Green spaces are distributed along radiation lines, and green spaces are among more than two functional axes in star-type cities. As large green spaces, urban green spaces are allocated between central and satellite cities. The cities of liner types, green spaces are developed along the transportation corridors (Shan et al., 2021). A vertical greening system is very important when considering compact cities to increase dense green spaces in urban areas. It calls green envelopes. Also, living greenery systems along building façades and buildings' roofs are significant points of view of urban city areas. Those concepts are very effective in reducing noise pollution in urban city areas. Figure 2 shows the living greenly system on the building façade.

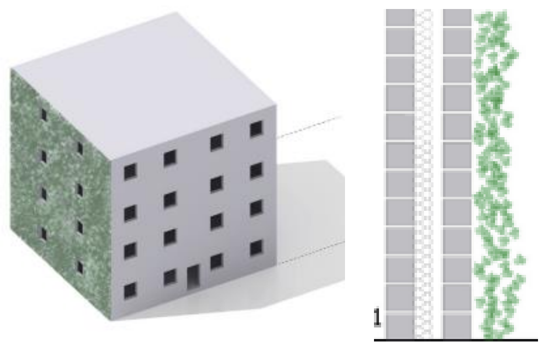

Figure 2. Living greenly system, (Shan et al., 2021)

3.2 Noise Absorption by Green Spaces

Several characteristics of plants such as the composition and texture of trees, help reduce traffic noise by certain amounts (Science, 2021). A Group of trees reduces road traffic noise levels than that have been grown alone. Tree parts like leaves, branches, wood, and stems absorb sound waves; flesh leaves can absorb sound due to their dynamic surfaces. Mainly, the leaves of trees and bark effect to absorb noise effectively. The most reason being leaves spread in a large space comparing tree bark. Leaves play a more significant role absorbing traffic noise levels (Dobson and Ryan, 2000). The amount of noise absorption by tree leaves on the surface area of leaves, tree depth, and noise absorption coefficient of leaves. Noise absorption will depend on the properties of the leaf-like size, thickness, and texture (Li and Kang, 2020). Large and thick leaves absorb more noise than narrow-width leaves (Ow and Ghosh, 2017). Increasing green areas is a very effective and less expensive method to reduce road traffic noise in urban cities. Previous studies have mentioned that leaves absorb noise at a higher frequency than at a low frequency (Watanabe and Yamada, 1996).

Group of trees, shrub/shrubs, and ground-covering vegetation absorb more noise than plants that grown alone (Kalansuriya, Pannila, and Sonnadara, 2009). Based on the result of Utami Retno's research, it has been identified that the composition of trees, shrubs, and bushes were more effective in decreasing road traffic noise by up to 12.25% (Java, 2013). According to Guilia's and Gupta's research, moderate green belts reduce the noise by 9-11dB (Gulia and Gupta, 2016). To identify noise absorption from green areas, researchers have used a method by establishing noise meters in front of tree belts and inside of and inside of tree belts, as shown in Figure 3 that examined noise absorption by different vegetation types. Finally, linear equations have been found to calculate noise absorption by using the distance between vehicles and trees. In this research, consideration was made about 2D noise levels, and that method can be improved to identify noise absorption by trees in 3D spaces (Pudjowati, Yanuwiyadi, and Sulistiono, 2013). The equations for noise absorption in this research, as shown in Table 1.

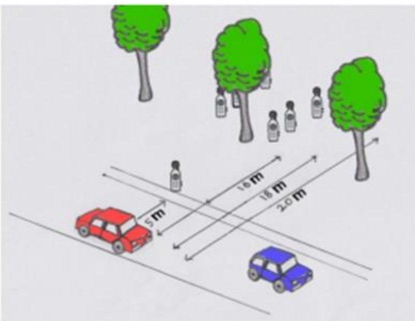

Figure 3. Position of noise level meters, (Pudjowati, Yanuwiyadi, and Sulistiono, 2013)

Vegetation	Noise Reduction Equation
Pithecellobium dulce	y=2.67ln(x)+2.18
Samanea saman	y=1.77ln(x)+0.95
Tectona grandis	y=4.60ln(x)-7.91
Pterocarpus indicus	y=3.77ln(x)-6.52

Table 1. Noise reduction equations, (Pudjowati, Yanuwiyadi and, Sulistiono, 2013)

Where, y is noise reduction by trees, and x is the distance from the vehicle to the noise level meter. These equations can be used to identify the relationship between noise absorption level and tree crown. The tree crown volume can be relatively calculated using the following equations 1 and 2. These equations consider whether the leaves of trees are broad leaves or needle leaves (Zhao et al., 2021). L is crown length, and D is the diameter of a crown footprint.

$V=\frac{3}{4}*\pi*L*(D/2)^2$, broad leaf (1) (Zhao et al., 2021)

$V=\frac{1}{3}*\pi*L*(D/2)^2$, needle leaf (2) (Zhao et al., 2021)

Reacher J.Acoult has formulated a new equation to identify the sound absorption of leaves in 1996. The noise absorption coefficient of leaves, depth of trees, total surface area per unit volume, and frequency of road traffic noise are considered as parameters in this equation. The coefficient of noise absorption of leaves is changed by several factors like the size, the thickness, and the texture of the leaves (Watanabe and Yamada, 1996). Therefore, coefficient of noise absorption of leaves must be examined with standards experiments (Jamaludin et al., 2021). Equation 3 shows the way to calculate noise absorption by leaves of trees. Where, G is the coefficient (frequency absorption factor of leaves), F is the total surface area of leaves for unit volume, L is the depth of tree, and f is the frequency of the noise levels.

A=-10log {1-((G*F*L*f^ (1/2))/8)} (3) (Watanabe and Yamada, 1996)

3.3 Green Spaces Visualization in 3D

A virtual 3D city model represents geo-referenced urban data of a 3D environment. It is integrated a 3D city model with geoinformation in complex urban spaces (Döllner, Baumann, and Buchholz, 2006). Representing the exact shape of the green area in a 3D city model is a significant feature in accurately calculating noise absorption, because trees are the main factor in absorbing road traffic noise levels in urban areas (Neuenschwander, Wissen Hayek and Grêt-Regamey, 2014). To visualize the true volumetric shape of trees using 3D on built space, Light Detection and Ranging (LiDAR) data can be used. LiDAR provides vegetation information from the top of the canopy down to the ground level. A major limitation of Geographical Information Science (GIS) is that it only includes surface visualization that excludes below the canopy. It means data below the canopy may be lost, and cannot be represented by the Digital Surface model (DSM) for visualizing green areas in the urban city model. A solution for this limitation is using 3D graphics software packages that can plot data in 3D space to represent the green spaces. The “″ ″″ gnuplot ″’ ″″ software allows plotting data in 3D space (Anderson et al., 2018). Figure 4 shows the basic limitation of tree visualization using the DSM model, it only provides (two and half-dimensional) 2.5D visualization of data. Figure 4a and Figure 4b represent relatively raster and vector visualization of green spaces in DSM. When using (two-dimensional) 2D maps, the trees' height can be implemented using only colour code, and Figure 4c shows 2D visualization.

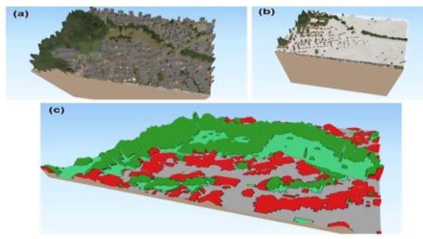

Figure 4. Visualization of the green area using gnuplot, (Anderson et al., 2018)

Figure 5 represents the visualization of green areas by gnuplot software, meaning all tree features from canopy to ground level.

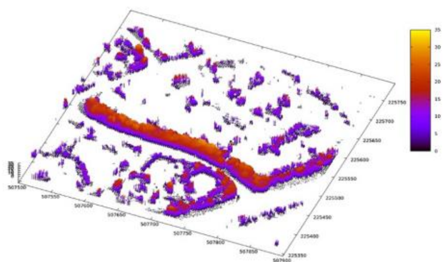

Figure 5. Visualization of the green area using gnuplot, (Anderson et al., 2018)

4. DISCUSSION

Green spaces are situated far away from roads. It does not significantly reduce road traffic noise pollution in urban city areas. Neither isolated trees nor centralized green parks are not a better impact on absorbing noise levels. If the trees are situated like a green belt at least 50m from the road, it will significantly reduce traffic noise pollution (Ramyar, 2019). Traffic lands with high road density are a major contributor to noise pollution, and mixed land-use like residential and commercial lands inspire traffic noise pollution. When examining road traffic noise levels in urban functional zones, noise levels have been reduced where green spaces are available (Han et al., 2018).

The buildings' lower height and wide streets greatly resist noise reduction. Moreover, properly maintained green spaces among lower-height buildings and along the wide roads will provide a significant process to reduce noise levels further. Integrated urban buildings to the urban acoustic environment are very important for future urban planning, and vegetation on urban buildings' façades show various functions to develop the ecosystem in urban areas. The vegetation on the building façade acts as a material to absorb noise levels. Vegetation on the building can be called vegetation envelop. It can be applied to the buildings' balconies and roof areas to reduce traffic noise pollution (Yang and Jeon, 2020). Green plants on the roof provide a noise barrier, and a roof with a 12cm green layer reduces 40 dB noise level while a 20cm green layer reduces 46 - 50 dB (Science, 2021).

Green spaces can reduce noise, because of the incident of absorption, refraction, and reflectance. When considering noise refraction and reflectance are very low compared with absorption. The parts of trees like bark, branches, and leaves effects noise absorption. Because leaves spread in large volumes than bark and branches, they provide a major impact on absorbing road traffic noise. The vibration of leaves is a very important point of view for absorbing noise levels. A leaf's thickness, size, and mass greatly influence noise absorption (Yuan *et al.*, 2019).

Due to the urbanization and concept of compact cities, the green spaces are reduced. So, the replantation process of green areas is conducted by some developed countries. Identifying urban forms of green areas is very important before starting the replantation process of the green regions. Advance remote sensing techniques can detect urban forms of any city area. If the shape of the green areas is related to urban forms, it greatly reduces noise pollution (Shan et al., 2021). When designing green belts along the roads, the size of the green belts should be identified with experiments (Koprowska et al., 2018). Proper noise equations should be used to calculate noise absorption by leaves. Several researchers have used a simple and flexible method to identify noise absorption by leaves that the noise level meter was established in front of the tree belt, behind the tree belt, and inside the tree belt. The noise levels inside and behind the tree belt were compared with the noise level in front of the tree belt to identify the noise absorption by trees. It has found a relationship between distance from the noise source to the observation point, the width of the tree belt, and vegetation types. Furthermore, the size and density of tree belts affect noise reduction. But there have been no comparisons between properties of leaves like size, mass, and texture. The reason is leaves can have a significant impact on absorbing noise. Considering these properties of leaves' impact on noise levels, the final output will be more accurate than this. Equation of J.Acoult has been shown about noise absorption coefficient of leaves, depth of the tree, the surface area of leaves, and frequency of the noise levels. This equation greatly impacts improving the accuracy level of noise absorption. It was a recommended method to find the noise absorption coefficient of leaves in the laboratory, and the impact of different noise frequencies on leaves (Watanabe and Yamada, 1996).

Traditional survey techniques are not enough to find the properties of trees to identify noise absorption. The surface area of leaves is not easy to calculate using conventional survey techniques. Light detection and ranging (LiDAR) has been recommended to detect features of trees, and those concepts can be embedded with noise absorption equations for identifying noise absorption levels. Figure 6 shows that LiDAR points to clouds of trees, and Figure 7 shows how to identify crown depth (tree depth) and crown diameter during when post-processing stage.

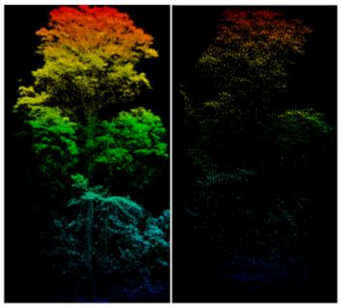

Figure 6. LiDAR points cloud of tree, (d'Oliveira et al., 2020)

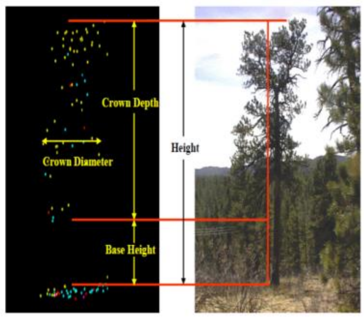

Figure 7. Identify values to parameters to calculate noise absorption, (Zhang, Zhou, and Qiu, 2015)

Geographical Information System (GIS) software provides a limitation to visualize trees from both vector and raster formats. Visualizing green areas via DSM does not represent all the data under the top of the crown. Surface visualization is insufficient to identify trees' features and calculate leaves' noise absorption. If green areas can be visualized as points to identify all the features, it will be foremost for the calculations.

5. CONCLUSION

Traffic lands spread based on the urban forms of the cities. Especially, mixed land use and buildings imply road traffic noise pollution. Traffic noise pollution is 90% of noise pollution in urban cities. Therefore, controlling noise pollution is essential for improving the living conditions of citizens. Green spaces provide a huge impact on absorbing noise pollution. When designing green spaces, the urban forms of the cities should be considered to get an optimum result. Further, increasing the living vertical greenery areas is vital in compact cities.

Especially leaves of trees act a main role to absorb the noise. Therefore, identifying the noise absorption frequency of leaves are very important, and impedance tube method has been recommended for determine noise absorption frequency of leaves. When examining the noise absorption coefficient of leaves, the coefficient may vary with different types of trees. Furthermore, some types of the same vegetation provide different values for coefficient, because of the different sizes and mass of leaves. So, the average value of the coefficient must be taken into the calculation. Green spaces are more effective in reducing the road traffic noise from the 2nd floor to higher floors of a building. As described in Figure 8, trees are not enough for noise reduction on the first floor of a building. Furthermore, bushes or wall noise barriers can be used to reduce noise levels.

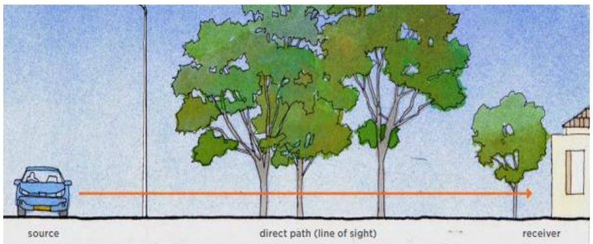

Figure 8. Noise emissions from a source point to the first floor of the building, (Noise wall design guideline, 2017)

The equations are used to identify noise absorption by trees that need to be embedded with a standard road traffic noise equation for determining actual traffic noise levels after absorbtion by green areas. The noise absorption equations are linear, and visualizing noise levels in 2D city space is not an issue from these equations. But when integrating noise reduction of green areas with the 3D city, a new method should identify to embed equations in 3D space. As an example in Figure 9, the noise levels from the noise source to tree spaces can be found using standard road traffic noise equations, and then noise reduction by green areas can be identified by the J.Acoult equation. Finally, the noise level from the end of the tree space to the building can be calculated using a standard road traffic noise equation.

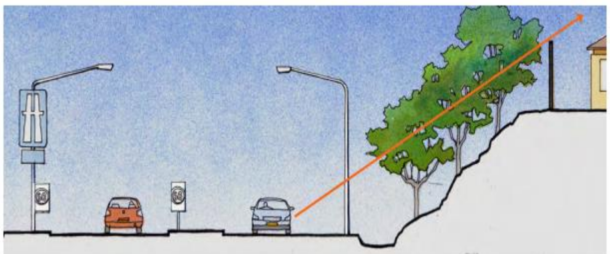

Figure 9. Noise emissions from a noise source to building through green space, (Noise wall design guideline, 2017)

The laser scanning technology has been used in many applications, such as virtual campus (Salleh et al., 2021), geomarketing (Azri et al., 2020; Azri et al., 2016), and heritage maintenance (Mohd et al., 2017), and proved to be more accurate than other techniques (Hairuddin et al., 2019). Furthermore, the laser scanning technology can easily identify the properties of trees like the area of leaves, very accurately. Otherwise, high-resolution drone images with different flight heights can be adapted to detect trees with complete details. But visualizing trees using a DSM on a GIS environment is impossible because it cannot be represented very preciously below part of the trees. So, the point plotting method must be embedded in the GIS environment. According to the equation of noise absorption by leaves, the amount of noise absorption depends on the ratio between the leaves' surface area and the tree's canopy volume. Therefore, an accurate 3D visualization of trees is vital.

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